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Multiple-Pole Electric Machine

Field of the Invention

The present invention relates to an improved electric machine with a medium frequency and a low speed, particularly to a multiple-pole electric machine.

Background of the Invention

In general, there are two kinds of medium frequency electric machines in prior art: one is of an inductor in which a higher harmonic is induced under a DC excitation; and the other is of a claw pole. The disadvantages of the former are a larger size, a higher cost and a lower efficiency due to utilizing its harmonic field. The disadvantages of the latter are: although it has more poles, the loss of power is too much under a higher frequency due to its longer magnetic circuit of the claw-pole structure. In addition, electric machines in the prior art are of less number of slots due to few poles. Moreover, also to avoid the performances deteriorating due to induction leakage, the slot cannot be too deep for obtaining a higher magnetic potential, and a structure of non-straight slots which has a narrower opening and a wider interior is often used to accommodate more turns of windings. The disadvantages of this structure are that: the increasing of the temperature is limited to result in the output lower, because some turns in each slot must be located at the center of the slot and can't contact the wall of the iron core. Thus the heat dissipation of this windings has to pass through a longer path of the insulating medium until reaching the iron core which plays a strong role of heat dissipation.

To overcome the above drawbacks in the prior art, the present invention is to provide a novel electric machine of a medium frequency, particularly an electric machine with more poles.

Summary of the Invention

An object of the present invention is to project a multiple-pole electric machine comprising a rotor and a stator, the rotor being of permanent magnet, or of electric excitation, or of induction, the number of poles in the rotor being 8 or more than 8, a

plurality of wave windings being arranged in a plurality of slots correspondingly, and each turn of the windings contacting the wall of the iron core of the stator. wherein the wave windings are formed by wires in the form of layers between which is an equal pitch or an unequal pitch;

Another object of the present invention is to provide a multiple-pole electric machine comprising a rotor and a stator, the number of poles in the rotor being 8 or more than 8, the armature core of the stator being slotless, and a winding which is a surface wave winding being arranged on the surface of the armature core in a single layer with an equal pitch or a unequal pitch.

Still another object of the present invention is to provide a process for pulse exciting in a permanent magnet electric machine, comprising: a. setting a one or more phase windings in the armature of stator as exciting windings, wherein each exciting winding is provided with a charging circuit and discharging circuit for exciting; b. providing a trigger discharging circuit to each discharging circuit for rendering the triggering of the trigger discharging circuit to occur at a time the winding is facing a magnetic pole within a phase angle of 30°.

Compared with the prior art, the electric machine according to the present invention is of the advantages of saving materials, a larger output and a higher efficiency, and a simple process for forming a winding. Moreover, the invention can also be used in other fields in addition to medium frequency machines.

Brief Description of the Drawings

Fig. 1 is a sectional view of partial armature core laminations of a slotted stator and windings according to the present invention, in which the winding is of a double- strand in a layer;

Fig. 2 is a sectional view of partial armature core laminations of a slotted stator and windings according to the present invention, in which the winding is of a single strand in a layer;

Fig. 3 is a developed view of an inclined structure between poles of a rotor and slots of a stator of a slotted multiple-pole p-m machine according to the present invention;

Fig. 4a is a developed view of a winding not lapped at the extension according to the invention, in which there are 2 phases (m);

Fig. 4b is a vector graph of a current in the winding shown in Fig.4a;

Fig. 5 is a developed view of a pole-pitch wave winding of the present invention, in which the number of phases, m is 3;

Fig. 6 is another developed view of a pole-pitch wave winding of the present invention, in which the number of phase, m is 3;

Fig. 7 is a developed view of a wave winding partially lapped according to the present invention, in which m is 3 and k is 2;

Fig. 8 is a schematic sectional view of a portion of armature core laminations of the non-slotted stator and windings of the present invention;

Fig. 9 is a developed view of a surface wave winding not lapped at the extension according to the present invention;

Fig.10 is a developed view of a pole-pitch winding formed by a single strand according to the present invention, in which m is 2;

Fig. 11 is a view of a p-m rotor magnetized in the radial direction according to the present invention;

Fig. 12 is a vector graph of an exciting current and a potential of the armature of a synchronous electric machine according to the present invention;

Fig. 13 is a graph of a primary waveform of a potential of the armature of a synchronous electric machine according to the present invention;

Fig. 14 is a circuit diagram showing a reference direction of the current of the armature of a synchronous generator according to the present invention;

Fig. 15 is a circuit diagram of a pulse exciting in a synchronous p-m electric machine according to the present invention;

Fig. 16 is a graph showing a relationship between the discharging time of the exciting pulse and a phase voltage according to the present invention;

Fig.17 is a graph showing pulse parameters of a pulsing current for exciting according to the present invention;

Fig. 18 is a graph showing the reference time of a pulse discharging for exciting under three phases according to the present invention;

Fig. 19 shows an embodiment of a circuit for a pulse exciting according to the present invention; and

Fig. 20 is a structure view of an electric exciting rotor of a multiple –pole machine according to the present invention.

Detailed Description of the Invention

The present invention will be described in detail in conjunction with the accompanying drawings.

One embodiment of a multiple-pole electric machine according to the present invention comprises a rotor and a stator which is slotted. In this embodiment, armature core laminations of the stator and an arrangement of windings in the slot are shown in Fig. 1 and Fig. 2. As shown in the Figs, slots 101 or 201 occupied by windings is straight with an opening. The armature core lamination of the stator has a tooth portion 103 or 203 and a yoke portion 104 or 204. The sections of the windings in Fig.1 and Fig. 2 are indicated by 102 and 202, respectively. As shown in Fig. 1, there are 6 layers of the windings in each slot and each layer comprises double-strand windings consisting of solid wires. As shown in Fig. 2, there are 4 layers of the windings in each slot and each layer comprises one-strand windings consisting of solid wire. From Fig.1 and 2, wires in each turn of the windings except for an insulating layer directly adjoins the wall of the armature core so as to improve the performance of a temperature change. In the case of the double-strand windings, a wedge can be provided at the opening of the slot to decrease loss of power. The rotor used in the embodiment may be a p-m one, an electric excitation one, or of an induction one.

The armature winding is formed under a principle that it is winded in different layers and to keep the portion of the extension as short as possible. Thus, the winding is formed as a wave winding with an equal pitch or an unequal pitch. The winding used in the invention comprises a wave winding without lapping at the extension; a pole-pitch wave winding; and a wave winding with an overlapping.

In the first kind of a wave winding, each pole comprises m slots. Chinese patent 94116888.1 has disclosed such a winding in which m is 3. In the present invention, m may be an integer. Fig.4a shows a developed view of a winding on a layer in a straight

slot in which m is 2. In this case, m sets of the windings for m phases are arranged into m adjacent slots in the same direction without being lapped at the extension. 407 represents a pole of the rotor, and 408 is a tooth of the stator. Each pair of poles corresponds 4 slots of the stator. The electric angle between two adjacent slots is 90°. Windings 401 and 402 (m=2) located in the same layer are arranged to be over the first adjacent two slots in the same direction from the downside to the upperside, not lapped at the upper extensions, and then arranged into the adjacent third and fourth slots in the same direction from the upperside back to the downside without being lapped each other. 403, 404, 405, and 406 respectively represents current directions in the winding in the adjacent four slots at a time. Their vectors are shown in Fig. 4b, in which vectors 413 and 414 correspond to currents 403 and 404 in the same winding 401 as shown in Fig. 4a, and their resultant vector is J. Vectors 415 and 416 respectively correspond to currents 405 and 406 in the same winding 402 as shown in Fig.4a, and their resultant vector is also J. By selecting the polarities, windings 401and 402 may be arranged in series or in parallel to obtain a resultant phase winding with a phase vector in the direction J, which represents a vector of the winding on this layer. Four phase windings respectively having phases 0°, 90°, 180°, and 270° can be obtained by translating a phase winding in a layer a slot four times. In particular, by translating a pole span a phase winding having a phase-shift of 180° is obtained.

The second kind of a wave winding is a pole-pitch wave winding. Each pole comprises m slots, where m is the number of phase. Figs 5 and 6 show two kinds of such windings in which m is 3. Each of windings 501, 502 and 503 in Fig. 5 for three phases has a pitch equal to a pole span. A developed plan of a tooth of the slot is indicated as 504. The three windings 501, 502 and 503 located at the same layer are lapped with each other at the extension. Thus, there is a sufficient space left at the extension to wind wires. Similar to Fig. 5, in Fig. 6, a developed plan 604 correspond to the developed plan 504 in Fig. 5, and windings 601 and 602 correspond to the windings 502 and 503, respectively. A winding 603 is formed by translating winding 503 in Fig. 5 a pole span (three slots). Therefore, the winding 603 has a reverse phase to the windings 503.

The third kind of a wave winding is a partially lapping winding. Such a wave

winding has partial features of both above two kinds of windings. The winding in one phase is arranged without being lapped at the extension and is of a phase belt and more than 0°. Another phase winding can be formed by translating a phase winding onto another phase band. Phase windings at the same layer are lapped at the extension, as shown in Fig. 7. In Fig. 7, there are three phases (m is 3). The phase belt of each phase occupies 2 slots. In this case, each pole comprises $m \times k = 3 \times 2 = 6$ slots. The width of the phase belt is that of 1 slot (k-1), i.e. its electric angle is 30°. As a result, the harmonic performance is improved. The developed plans of two teeth between which there is a span occupied by a pair of poles are indicated as 707 and 708, respectively. Windings 701and 702 constitute a phase winding which is winded in a way similar to that shown in Fig. 4a. That is, they are arranged to cross two adjacent slots in the same direction without being lapped at the extension. In this case, however, the number of the slots crossed is more than that in Fig. 4a although a pole span has been crossed. The windings 703 and 704 for the next or second phase can be obtained by translating the windings 701and 702 two slots. Similarly, windings 705 and 706 for the third phase can be obtained. Similar to that in Fig. 6, the three sets of the windings for the three phases are lapped at the extension. Alternatively, they may be arranged according to the manner shown in Fig. 5. The skilled in the art should appreciate the case when m and k are any other integer.

The above three kinds of wave windings arranged in different layers including windings 401 and 402 in Fig. 4a, windings 501, 502, and 503 in Fig. 5, windings 601, 602, and 603 in Fig. 6, and windings 701 through 706 in Fig. 7 are described for those arranged with a stand or double-stand wire in layers in a slot, which are shown as 202 in Fig. 2 and 102 in Fig. 1.

The above arrangements of the windings are simple and are easily automated and may reach an optimal design to make the length at the extension minimal, thereby saving copper, decreasing induction leakage, and improving the performance of medium and high frequency. Also, all the wires of the windings contact the wall of the iron core to create a better heat dissipation and a higher output.

It should be appreciated that the teeth in Figs 4a, 5, 6 and 7 have a rectangular contour, the developed plan 408 as shown in Fig. 4a is rectangular, and the developed

plan of the tile-like pole 407 of the rotor is also rectangular. This structure between the rotor pole and the stator slot is called as a straight one. In addition, in case the rotor is of a permanent magnet, an inclined structure between the pole of the rotor and the slot is formed, as shown in Fig. 3. The inclined structure may also be formed using the iron core with straight slots as shown in Fig.1 and Fig. 2. In Fig. 3, the developed plan of magnetic poles N and S of the rotor is rectangular, and has its axis 303. A developed plan 301 of the tooth is a parallelogram. The axis of the tooth is indicated as 304. The slot 302 is inclined. The inclination between the axis 303 and the axis 304 is indicated as an angle g. The length of the iron core is L, and the tooth span is T. It is noted that with this structure an improved wave shape may be obtained to decrease the electric-magnetic loss. Also, the key points of this structure lies in that the angle g is not 0. That is, the structure may be formed in a way that the slot of the tooth is rectangular, the developed plan of the pole of the rotor is a parallelogram and an angle between the axis of the pole and the axis of the tooth is kept g. A better harmonic performance can be obtained with the above two inclined structures.

According to the present invention, the optimal angle g should meet that: $L \times tg(g)$ is not more than 2T.

Another embodiment of the present invention is a non-slotted multiple-pole electric machine. Its rotor is of permanent magnet and its iron core of the stator is non-slotted, as shown in Fig. 8. A magnetic yoke 801 consisting of a non-slotted lamination, and a wire section 802 of a winding are shown in Fig. 8. Although the wire section 802 is circular in the Fig, it should be understood that the wire having a flat section may have a better effect. The wire of the winding is attached to the surface of the iron core adjacent to the air gap. The arrangement of the winding follows a principle that each turn of the wire of the winding contacts the iron core and makes its extension portion as short as possible. This arrangement refers to as a surface wave winding with an equal or unequal pitch in a single layer. Also, three kinds of windings are provided: the first is a surface wave winding without being lapped at the extension; the second is a surface pole-pitch wave winding; the third is a surface wave winding with being partially lapped at the extension.

The above surface wave winding without being lapped at the extension is shown in

Fig. 9, which shows a schematic developed view formed by developing the plan of a cylindrical air gap of the iron core along the circumference. Reference numeral 904 represents a portion of the iron core cylinder surface at the side of the air gap, L is the length of the iron core, and poles N and S of the rotor are indicated as 905. The pole span of a pair of poles is 2τ. Windings 901, 902 and 903 show the arrangement of the surface wave windings without being lapped at the extension in the case of k = 3. The windings 901, 902 and 903 cross the surface of the iron core vertically in the same direction and occupy a width of B on the surface (the width of a phase belt). A winding for a phase is formed by connecting windings 901, 902 and 903 in series.

A pole-pitch wave winding formed by a single strand is shown in Fig. 10, in which m is 2. The developed plan of the iron core is indicated as 1003. The length of the iron core is L. Windings 1001 and 1002 are formed with a respective single strand in the same manner for two phases. One of them can be obtained by translating the other one a half of a pole span (a phase shift of 90°). The windings 1001 and 1002 are lapped on points 1004 and 1005 at the extension. As shown in Fig. 10, the winding 1001 is above the winding 1002 and lapped therewith at the point 1004, while the winding 1002 is above the winding 1001 at the point 1005 and lapped therewith. The position of the windings 1001 and 1002 can be changed each other. The pole span of magnetic poles N and S of the rotor is τ. The disadvantage of the winding formed by a single strand is that the application ratio of the surface is lower. To increase the application ratio of the surface, it is recommended to use a method in combination of that shown in Fig. 9 with that shown in Fig. 10 in which the winding is partially lapped at the extension. Thus, windings 901, 902 and 903 for a phase as shown in Fig. 9 as a phase winding replaces each of windings 1001 and 1002 for two phases in Fig. 10 to form a surface winding including 2 phases (m=2), each phase comprising 3 strands of wires (k=3), and the width of the phase belt being B. This surface winding is characterized in that: k strands of the winding for each phase are not lapped at the extension, but lapped between the windings with a different phase at the extension. Those skilled in the art should understand the case when m or k is any integer.

The advantages of this structure are that: the manufacture of the iron core is simple and the materials are saved because it is non-slotted; and the waveform is better, the

noise is lower and the operation is silent and smooth because there is no effect of teeth and slots.

When the rotor is of permanent magnet as shown in Fig. 11, a radial air gap may be incorporated in the magnetic circuit. In Fig. 11, the rotor is provided with tile-like permanent magnets 1101. The yoke of the rotor iron core is shown as 1103, and the direction of the magnetic flux is shown by an arrow 1102.

Alternatively, the structure of the magnetic circuit may be axial. In this case, the structure of the electric machine is a disk type. Also, other usable magnetic pole structures in the prior art can be selected.

According to the present invention, there is provided a method for enhancing the exciting of a multiple-pole p-m electric machine of medium frequency, i.e. a method of pulse exciting. The method can be used to increase power of the above p-m electric machine. The method comprises the following steps of:

a. providing one excitation winding or more excitation windings on the armature, windings for a phase or for all m phases of the armature being preferably used as excitation windings; and

b. applying a pulsing current to each excitation winding at a time when a p-m pole of the rotor is coming in each cycle of the current to generate a pulsing magnetic field induced which enhances the field of the rotor, i.e. the permanent magnet being magnetized instantaneously by the pulse current to lead the flux in the air gap to rise that thanks to the effects of magnetic reluctance and resistance, so that the induced potential is increased.

The present invention will be described in detail with reference to a generator.

It has been well known that the phase F of the magnetic potential of exciting in a synchronous generator leads the potential Eo of the armature by 90° , as shown in Fig.12. A winding for a phase is of a waveform of the potential Ea as shown in Fig. 13. In Fig. 13, the potential reaches its positive peak at a time of T_2 and reaches its negative peak at time T_4, which means that the winding is exactly facing N pole of the rotor at T1, a time of zero passage, and exactly facing S pole of the rotor at T3, another time of zero passage. In the case of a p-m synchronous generator, when a winding Wa of a phase as shown in Fig.14 with a waveform of potential Ea shown in Fig. 13, whose positive

current is taken as a reference direction, is applied with an advanced positive exciting pulsing current Ip through an exciting circuit 1401 at a time of T1, i.e. 90° before the positive peak, as shown in Fig. 14, a flux in the direction of its permanent magnet pole is increased to thereby enhance the excitation. In the same way, a negative pulsing current –Ip may be applied to the winding Wa shown in Fig.14 at a time of T3 in Fig. 13, i.e. 90° after the positive peak, to enhance the excitation.

Fig.15 shows a circuit to implement the process for the pulse exciting to a multiple-pole p-m synchronous machine according to the present invention. In the Fig, 1501 is a winding for a phase, and includes a neutral point G, a terminal H whose phase potential is Ea and a tap M connected to the circuit. In general, M is coincided with H, i.e. no tap M. The exciting circuit comprises a discharging switch 1502, such as a thyristor, with a control terminal 1503, a capacitor 1504 for charging and discharging, a DC power device 1505 for charging, generally such as a rectification circuit for the phase voltage of the generator itself, and a buffer device 1506 for charging and discharging, such as a resistance or an insulating switch. The direction of the current during the charging is indicated by an arrow 1507.

Fig. 16 shows the primary wave of the phase potential Ea during the p-m generator with a pulse exciting circuit shown in Fig.15 being actuated. When t is T3, the phase angle θ is 0. θ1 and θ2 are a phase angle at a time before and after T3, respectively, and their maximum of the absolute value are 30° Fig.17 schematically shows the waveform of the pulsation current with a starting time Ts.

Refer to Figs 15, 16, and 17. When the control terminal 1503 in Fig. 15 is trigged at a time between θ1 and θ2 in Fig. 16 and Fig. 17, such as at Ts in Fig. 17, to make the charging switch 1502 on, the current 1507 has a pulse 1701 as shown Fig.17, whose width D, i.e. the phase difference between the time of Ts and a time when the waveform of the current drops to 10% of the peak, is not less 60 degrees.

In the case of a normal three-phase machine, all the three sets of windings for the three phases may be provided with the above exciting means. As a result, the phase potential can be increased by 30% by applying a respective exciting pulse to each cycle.

The direction of the exciting current in Fig. 15 can be reversed if the polarities in the related devices are reversed, and the starting time of Ts should be changed to around

T1.

Using different methods, the reference phase position θ and the reference time T3 for discharging can be tested to determine the starting time Ts.

One method in the prior art is phase position testing, in which the time of the peak or the zero passage of the phase voltage is tested, and a suitable Ts between $\theta 1$ and $\theta 2$ is obtained by means of a delay circuit.

Another method is using a position sensor. In this method, the position sensor, such as a Hall element, is embedded in a suitable position of the winding of the armature of the stator to test the coming time of the magnetic pole of the rotor. This also is well known in the prior art.

It is appreciated for those skilled in the art that the circuit shown in Fig.15 may also be used to a motor. The reference direction Ia in Fig. 15 is reversed when the motor is in the synchronous state. In this case, as long as the direction of current 1507 in Fig. 15 and the timing in Fig.17 are remained, the conditions of applying the pulse during the time of the pole coming are still met.

An embodiment of the method of enhancing the excitation for a p-m synchronous generator of three phases according to the present invention will be described below.

For the purpose of explanation, in this embodiment, the pole of the p-m synchronous generator is the same as shown in Fig. 11, the iron core of the stator is the same as shown in Fig. 1 or Fig. 2, and the winding may be any kind of the above wave windings with an equal or unequal pitch. The three windings for the three phases are in a sequence of a→b→c like the conventional. Fig. 18 shows the waveform of the voltages for a, b-phase with the phase voltage of a-phase leading that of b-phase by 120°, in which θ is a phase angle and t is a coordinate axle of time. Both points T1 and point T3 are the points of zero passage for the voltage of a-phase. The a- and b- phases have the same potential at 1801. The phase angle of point 1801 is the phase difference between the phase position $\theta 1$ and the phase position of point T3, and is exactly equal to 30. $\theta 1$ is used as a reference phase position, or reference time for discharging to the winding for the a-phase.

A circuit for charging and discharging of the a-phase is shown in Fig. 19. The phase sequence of the generator is a→b→c. In the Figure, G is a neutral point, 1901 is an

output terminal of the voltage for the a-phase, 1902 is a charging and discharging capacitor, 1903 is a charging power, which may generally be an alternating current power for the a-phase or the c-phase, 1904 is a diode of the circuit for charging, 1905 is a current-limiting resistance for charging, which also serves as a buffer resistance during discharging, 1906 is a thyristor with a gate 1907, 1908 is a control power taken from the b-phase, 1909 is a diode, resistances 1910 and 1911 form a shunt circuit to adjust the level of the trigger pulse, and resistance 1913 and Zener diode 1914 form a chopper circuit to make the voltage of gate 1907 have a adequate rate of rise. The diode 1914 also serves to protect the gate 1907. To adjust the resistance 1910 or 1911, the delay time from the phase position θ1 to T3 in Fig 18, i.e. Ts in Fig. 17 can be finely adjusted.

The circuit for charging and discharging of the other two phase, i.e. b- and c-phases are the same as the above. For example, the related phase positions for the b-phase may be obtained by shifting the respective phase positions in Fig. 18 and Fig. 19 backward by an order of phase. Namely, a-phase, b-phase and c-phase in Fig. 18 and Fig. 19 are changed to b-phase, c-phase and a-phase, respectively.

The advantages of this excitation are of a simple configuration, no electric brush, no change of the mechanical structure, lower power for the excitation, and higher output.

The present invention further provides a rotor structure for the electric excitation for the slotted multiple–pole machine. Fig. 20 shows a developed view of a winding and an iron core of the rotor.

In the medium frequency generator of claw- pole type in prior art, a centered magnetic circuit is formed in the iron core of the rotor to branch the flux to each pair of claw poles. However, in the iron core of the rotor of the present invention shown in Fig. 20, the iron core with the magnetic poles N and S consists of iron core lamination 2001. The pole span is τ. As shown in the Figure, the magnetic lines only pass through the adjacent two poles. Each pole corresponds to a slot in which the wires of the winding are winded in one or two strands on each layer according to the arrangement of the pole-pitch wave winding of the present invention. Fig. 20 shows the case of two layers of the winding in each slot and two strands (2002 and 2003 being sections of the wires) in each layer. The direction of outlet and inlet of the current is indicated as ⊙

and ⊗, respectively. The developed plan of the stator laminations is indicated as 2004. 2005 is a section of a winding of three layers in the slot. The number of the layer can be changed by adjusting the depth of the slot to obtain proper ampere turns for excitation. This structure has following advantages of a simple winding, good performance of temperature change and high efficiency.